Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-20, 2022

A 30 kW High Temperature Electrolysis Experimental Facility for Nuclear Hydrogen Production

Byung Ha Park *, Ho Sik Kim, Sung Deok Hong, Chan Soo Kim
Korea Atomic Energy Research Institute, 111, Daedeok-Daero, Yuseong-Gu, Daejeon, Korea
**Corresponding author: bhpark@kaeri.re.kr*

1. Introduction

Nuclear system is one of major non-carbon-emitting hydrogen production options. The high capacity factor of the nuclear system can reduce the cost of production. High temperature steam electrolysis (HTSE) is more efficient than room-temperature water electrolysis because some of the energy is supplied as heat, which is easily supplied from nuclear system. Operating temperature of proposed HTSE systems is over 700 ℃ [1]. Therefore, high temperature gas cooled reactor (HTGR) is a major option for the integration.

KAERI conducted various very high temperature experiments with helium experimental facility, which simulates primary helium loop in a very high temperature reactor. The facility can operate in the 900 to 950 ℃ with duty of 600 kW. KAERI is developing coupling technology for high temperature steam production system and HTSE. Construction of the integral test loop for a maximum capacity of 30 kW HTSE is in progress. Maximum 820 ℃ of steam is supplied from helium-water heat exchangers, which are helium-water evaporator, and helium-steam-air heat exchanger. The integral test using a 6kW HTSE system is planned in 2023.

2. Methods and Results

2.1 Integral test facility description

Fig. 1 shows a schematic of integrated 30kW HTSE system. Pressurized helium flow is maintained by circulator. Helium is heated from room-temperature to 950 ℃ by electric power. Purified water is pressurized by pump. It is evaporated by helium-water evaporator. The steam is super-heated by helium-steam-air heat exchanger. Typically volumetric 5% of hydrogen is mixed with steam for maintaining reducing atmosphere [2]. Sometimes nitrogen is used for purging gas. The mixture is supplied to the cathode of HTSE stack. The compressed air flow is controlled using mass flow controller. Air is pre-heated by electric power and heated to 820 ℃ by helium-steam-air heat exchanger. It is supplied to the anode of HTSE stack. The product from the cathode is mixture of hydrogen and steam. It is cooled, condensed and separated.

Fig. 2 shows overview of the helium experimental loop for a 30 kW HTSE system. Table I and Table II show design parameters for helium-water evaporator and helium-steam-air heat exchanger.

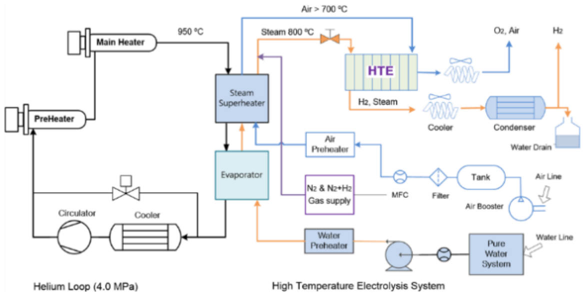

Fig. 1. Integrated 30 kW HTSE system process diagram

Fig. 2. Overview of helium experimental loop

Table I: Design parameters for evaporator

Helium-Water evaporator	
Primary fluid	Helium
Mass flow rate, kg/min	0.42
Inlet pressure, MPa	2
Inlet temperature, ℃	565
Outlet temperature, ℃	155
Secondary fluid	Water
Mass flow rate, kg/min	0.333
Inlet pressure, MPa	0.5
Inlet temperature, ℃	20
Outlet temperature, ℃	155
Required duty, kW	14.8

Table II: Design parameters for multi-stream heat exchanger

Helium-Steam-Air heat excahnger	
Primary fluid	Helium
Mass flow rate, kg/min	0.42
Inlet pressure, MPa	2
Inlet temperature, ℃	850
Outlet temperature, ℃	565
Secondary fluid 1	Steam
Mass flow rate, kg/min	0.333
Inlet pressure, MPa	0.5
Inlet temperature, ℃	155
Outlet temperature, ℃	820
Required duty (He-Steam), kW	8.1
Secindary fluid 2	Air
Mass flow rate, kg/min	0.19
Inlet pressure, MPa	0.11
Inlet temperature, ℃	155
Outlet temperature, ℃	820
Required duty (He-Air), kW	2.3
Total required duty, kW	10.4

2.2 Helium-Water evaporator

The evaporator is shell-and-tube type heat exchanger. High temperature helium flows through helical tube and water flows via shell-side. Fig. 3 shows an overview photograph of an evaporator. Solid oxide electrolysis cell (SOEC) is very sensitive to operating pressure condition in terms of integrity. Steam pressure is limited as compared with steam generator in conventional nuclear power plant. Steam is supplied to the cathode at almost atmospheric pressure.

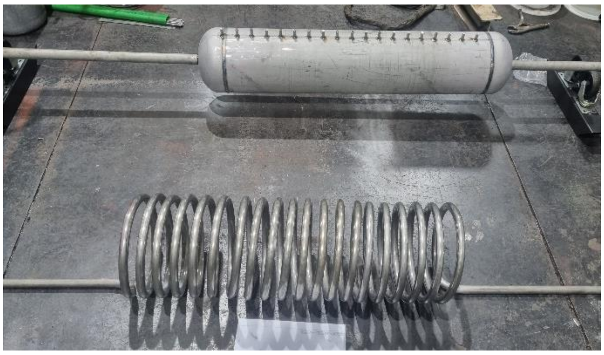

Fig. 3 Overview of evaporator

2.3 Helium-Steam-Air heat exchanger

Multi-stream printed circuit heat exchanger (PCHE) is developed and applied to the integrated system. Steam and air are simultaneously heated by helium. A compact heat exchanger can reduce number of heat exchangers and make better use of a space. Fig. 4 shows an overview modeling of a helium-steam-air printed circuit heat exchanger. The dimension of a helium-steam-air heat exchanger is 338×110×139 mm including headers.

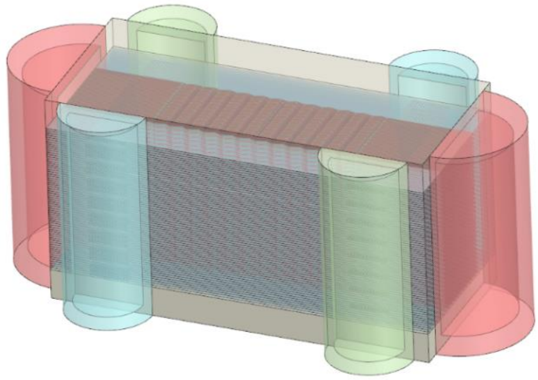

Fig. 4. Overview of helium-steam-air heat exchanger

3. Summary

KAERI is developing coupling technology for high temperature steam production and HTSE hydrogen production based on HTGR. The integral test facility for 30 kW HTSE system is under construction. Primary helium coolant is circulated in closed loop. It is heated by electric power. Water is evaporated and super-heated with helium heat exchangers. The evaporator is a shell-and-tube type heat exchanger. The super heater is a multi-stream printed circuit heat exchanger. It is designed that outlet temperatures of both steam and air are 820 ℃. Steam and air are supplied to the cathode and the anode of HTSE stack, respectively.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (Grant Code: 2021M2D4A2046777).

REFERENCES

[1] Y. Choi, J. Ahn, Study on Reversible Electrolysis Characteristic of a Planar Type SOFC, Trans. Of Korean Hydrogen and New Energy Society, Vol.28, No. 6, p. 657, 2017.
[2] J.E. O'Brien, J.L. Hartvigsen, R.D. Boardman, J.J. Hartvigsen, D. Larsen, and S. Elangovan, A 25 kW high temperature electrolysis facility for flexible hydrogen production and system integration studies, International journal of hydrogen energy, Vol.45, p.15796, 2020.